

APPLICATION OF MACRO MATERIAL FLOW MODELING TO THE
DECISION MAKING PROCESS FOR INTEGRATED WASTE
MANAGEMENT SYSTEMS

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April 1995

Presented at the
The Initial Conference on Solid Waste Management:
Thermal Treatment and Waste to Energy Technologies
April 18-21, 1995
Washington, D.C.

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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Application of Macro Material Flow Modeling to the Decision Making Process for Integrated Waste Management Systems

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ABSTRACT

Computer models have been used for almost a decade to model and analyze various aspects of solid waste management. Commercially available models exist for estimating the capital and operating costs of landfills, waste-to-energy facilities and compost systems and for optimizing system performance along a single dimension (e.g. cost or transportation distance).

An alternative to the use of currently available models is the more flexible macro material flow modeling approach in which a macro scale or regional level approach is taken. Waste materials are tracked through the complete integrated waste management cycle from generation through recycling and reuse, and finally to ultimate disposal.

Such an approach has been applied by the authors to two different applications. The STELLA simulation language (for Macintosh computers) was used to model the solid waste management system of Puerto Rico. The model incorporated population projections for all 78 municipalities in Puerto Rico from 1990 to 2010, solid waste generation factors, remaining life for the existing landfills, and projected startup time for new facilities. The Pacific Northwest Laboratory has used the SimScript simulation language (for Windows computers) to model the management of solid and hazardous wastes produced during cleanup and remediation activities at the Hanford Nuclear Site.

INTRODUCTION

Computer models have been used for almost a decade to model various aspects of solid waste management. Computer models should be used to provide statistical and economic data to assist in the decision making process. They supplement but do not replace expert solid waste engineers and planners.

Two basic approaches have been used to develop computer models. The first approach is to develop generic computer applications that can be run by technically competent personnel in the solid waste management field who are not necessarily computer programmers. The second approach is to use standardized "software tools" to develop a custom made model for a specific situation. Such a model requires close coordination between the software developer and the user.

Several generic models have been developed. These models all have standard input screens for data entry, and produce standardized output reports. One of the first models of this type was the Solid Waste Financial Model developed by the author for the California Integrated Waste Management Board in 1985 (1). The model was based on the widely used Lotus 1-2-3 spreadsheet program. It was designed to be used by individual cities to help estimate the costs of various solid waste management options. In 1988, another generic model, WastePlan, was developed by the Tellus Institute (2). A similar program, GIGO (Garbage In - Garbage Out), based on the EXCEL spreadsheet program, is under development at the University of California, Davis (2).

Results with these generic models have been mixed. All of them require significant staff time to organize and load the required data on waste composition, quantities, local labor and capital costs, etc. In Michigan and New York, many communities provided free copies of WastePlan by their state solid waste agencies, have not used it due to the time requirements for data loading and interpretation of the final results (2). A similar situation occurred in California with the Solid Waste Financial Model. Although the model was designed for use by individual communities, the principal users were consultants who were willing to devote the training time to effectively use the model.

The second approach to modeling is to develop customized applications for specific situations. An example of this approach was the Graphical Integrated Solid Waste Management Model developed by the author in 1990 for Brown and Caldwell Consultants and the Puerto Rico Solid Waste Management

Authority (3). The model was developed in conjunction with a revision of the Island-wide Master Plan. The model was custom developed to manage the time-phased closure of existing non-complying landfills and the construction and operation of replacement facilities. The model used the STELLA simulation language on the Macintosh computer.

Pacific Northwest Laboratory has developed a similar custom modeling technique using the SimScript simulation language (for WINDOWS computers) (4). The modeling approach used is more universal than the models previously discussed because individual materials can be tracked from raw material extraction, through manufacturing, use, and eventual waste generation and/or recycling. This approach is known as Macro Material Flow Modeling.

GRAPHICAL INTEGRATED SOLID WASTE MANAGEMENT MODEL FOR PUERTO RICO

The Commonwealth of Puerto Rico Solid Waste Management Authority (SWMA) contracted with Brown and Caldwell Consultants to prepare a computer model for tracking solid wastes using the STELLA computer language on the Macintosh microcomputer. As part of an earlier contract, Brown and Caldwell had assisted SWMA in preparing a Site Facility Plan which summarized the existing solid waste management system in Puerto Rico and presented a new system of regional landfills, transfer stations, and waste-to-energy plants. The model is a simulation of that Plan which incorporates population projections for all 78 municipalities in Puerto Rico from 1990 to 2010, solid waste generation factors for all municipalities, data on remaining life for the existing landfills, and projected startup time for the new landfills and waste-to-energy plants.

The STELLA Language

STELLA is a commercially available programming language which runs on the Macintosh computer. It combines features of a computer aided design program, a spreadsheet, and a conventional programming language. The most important feature of STELLA is that it is programmed graphically as a logic diagram. The program is generated by the logic diagram. Thus the diagram and the program are always in agreement. In conventional programming, the logic diagram (or flowsheet) is used by programmers as an outline. Since it is a paper document, the finished program may not actually match the logic diagram. Spreadsheets, although easy to construct, are difficult to edit since the programming logic is hidden behind the spreadsheet cells. With a STELLA program, the logic diagram always accurately represents the structure of the model. The logic diagram can be easily understood by non-programmers.

STELLA is programmed by constructing a flowsheet on the computer screen using graphical elements as shown in Figure 1, the logic diagram for the municipal solid waste (MSW) flow in the City of San Juan. The rectangle represents a "stock" or accumulation of material. In this case, the total MSW deposited at landfill 51. The circles represent "converters", algebraic expressions or constants. The arrow with double lines represent a "flow" of materials. The associated circle contains algebraic logic to control the flow. Finally the single line arrows represent logical connections between the flowsheet elements. Thus the population of San Juan (PopSJ) affects the yearly MSW generation in San Juan (MSWSJ).

STELLA Model - Existing MSW System.

The STELLA model for Puerto Rico was prepared in two parts, (1) a simulation of the existing system, and (2) a simulation of the proposed system. STELLA logic diagrams for the existing San Juan MSW system is shown in Figure 1. It is typical of the other 78 municipalities modeled. The converter (circle) labeled PopSJ is a graphical function which contains the population data for San Juan. It is linked to a "ghost" converter, or copy, labeled time_in. This provides time input to the model from 0 to 20 years in 1 year increments. The PopSJ function is saved in the STELLA model as an equation:

$$\text{PopSJ} = \text{graph}(\text{time in}) \\ (0.0, 415399), (5.00, 464144), (10.0, 393858), (15.0, 382210), (20.0, 370562)$$

The equation shows that the population at year 0 = 415,399 and so on. STELLA interpolates the yearly values. Graphical functions can also be drawn freehand. STELLA automatically converts the graph into numerical data.

The converter labeled MSWSJ, calculates the municipal solid waste (MSW) generated yearly in San Juan (in tons/year) using the equation below:

$$\text{MSWSJ} = \text{MSW_facSJ} * (300/2000) * \text{PopSJ}$$

The equation calculates MSWSJ by multiplying the population (PopSJ) by the daily MSW generation in lb/cap-day (MSW_facSJ). The arithmetic equation (300/2000) converts lb/cap-day into tons/day (assuming 300 days per year production). MSW_facSJ is a constant, 4.9 lb/cap-day. (Note: These constants and assumptions were specified by the client, SWMA. Any user specified days production per year and MSW generation rates can be used.)

The MSW "flows" to the landfill which is shown as the rectangle or stock labeled LF51SUM (for landfill #51). The flow is controlled by the converter LF51 which contains the equation:

$$LF51 = IF (LFT_51 = 0) OR (LFT_51 - TIME \leq 0) THEN 0 ELSE MSWSJ$$

This is a logical equation which states "If the landfill life remaining for landfill #51 (LFT_51) is equal to 0, or if the landfill life remaining minus the current model time (TIME) is equal to or less than 0, then, the MSW going to landfill #51 (LF51) is 0, otherwise it is equal to the MSW generated in San Juan that year (MSWSJ)". The constant LFT_51 equals 4, thus for years 0, 1, 2, and 3, LF51 will equal MSWSJ, and the MSW will flow to landfill #51. At year 4 (ie 1994), no MSW will flow to the landfill.

The converter LF51def contains the equation:

$$LF51def = MSWSJ - LF51$$

If LF51 is equal to 0 (as it would be in years 4 on), then the landfill deficit (LF51) is equal to the MSW generated that year (MSWSJ). The deficit represents MSW which is in excess of the projected life of the landfill.

For ease in comparing the simulation of the existing Puerto Rico MSW system with the proposed system, the 78 municipalities were grouped into the same 20 zones which will be used in the proposed system. San Juan is the only municipality located in Zone 1. The logic diagram shown in Figure 2 adds all the deficits generated in Zone 1.

The converter Z1def contains the equation:

$$Z1def = LF51def$$

The stock Z1defSUM contains the equation:

$$Z1defSUM = Z1defSUM + dt * (Z1def) \\ INIT(Z1defSUM) = 0$$

This equation calculates the accumulated sum of the Zone 1 deficit as the time increment is changed (ie from year 0 to year1, etc.). The second line of the equation initializes the sum to 0 at time 0.

STELLA Model - Proposed System

The Solid Waste Management Authority (SWMA) has proposed that many of the existing landfills be closed and that a regionalized system of 20 solid waste zones be developed. The zones will incorporate state-of-the-art landfills, transfer stations, and in some cases waste-to-energy plants. As conceived by SWMA in 1990, the system did not incorporate recycling, composting, and other landfill diversion technologies, but if SWMA's solid waste strategy changes, the model can easily be modified to reflect these diversions, and the resultant extension of landfill life.

The logic diagrams for the proposed system are more complex than the existing system because they incorporate waste-to-energy plants and a series of transfer stations. The logic diagram for Zone 1, the City of San Juan is representative of the other Zones and will be discussed.

The logic diagram is shown as Figure 3. The waste flow is either towards the waste-to-energy plant or to the deficit converter. The converter Z1_SJWTE contains the following logic:

$$Z1_SJWTE = IF (SRT_SJ = 0) OR (SRT_SJ - TIME \leq 0) THEN MSWSJ ELSE 0 \\ SRT_SJ = 4$$

The logical equation Z1_SJWTE routes the waste stream to San_JuanWTE or to Z1def by comparing the value of SRT_SJ (the start up time for the San Juan waste to energy plant) with the Time running in the Model. If Z1_SJWTE is equal to 0, then the deficit equation below applies:

$$Z1_{def} = MSWSJ - Z1_SJWTE$$

If $Z1_SJWTE$ is equal to $MSWSJ$, then the equations below balance the waste stream between ash (SJASH) and combustion (SJCOMB). It was assumed that 25% of the waste stream would be converted to ash.

$$SJASH = Z1_SJWTE * .25$$

$$Z1_SJWTE = \text{IF} (SRT_SJ = 0) \text{ OR } (SRT_SJ - TIME \leq 0) \text{ THEN } MSWSJ \text{ ELSE } 0$$

$$WTE_{facSJ} = Z1_SJWTE * .75$$

Similar logic is used for the Guaynabo waste-to-energy plant which shares a common ash landfill with the San Juan waste-to-energy plant. Note that the waste streams from six transfer stations are added together before entering the Guaynabo WTE plant.

Uses of the STELLA Model

The STELLA model developed for Puerto Rico is being used to help schedule the design and construction of the new landfills, transfer stations, and waste-to-energy plants recommended in the Site Facility Plan. One of the most important uses of the model is the monitoring of the timing and magnitude of deficits as the existing landfills reach capacity. The deficits show which municipalities in the system have the most critical need for new facilities.

Output from the model can be in graphical form or as spreadsheet compatible tables which can be transferred to other Macintosh applications such as spreadsheets (EXCEL) and word processors as ASCII files. Through the use of commercially available translator programs such as MacLink-PC, output data can also be transferred to standard MS-DOS or WINDOWS applications such as LOTUS 1-2-3 and WORDPERFECT. Consideration is being given by the software developer to producing a MS-DOS or WINDOWS version of STELLA to run directly on IBM and IBM-compatible PCs.

MACRO MATERIAL FLOW MODELING

The modeling approaches used in the Puerto Rico Model above and in the earlier Solid Waste Financial Model and Waste Plan Model are all focused on managing solid waste after generation. None of the models discussed have incorporated waste reduction, the highest level of the waste management hierarchy. The more flexible Macro Material Flow Modeling (MMFM) approach, in which a macro scale or regional level approach is taken, can incorporate waste reduction. Materials are tracked through the complete integrated waste management cycle from waste reduction, generation, collection, through to recycling and reuse, and finally to ultimate disposal. Pacific Northwest Laboratory has used such a methodology for several years to track and manage hazardous and solid wastes produced during cleanup and remediation activities at the Hanford Nuclear Site.

The basic approach of MMFM is to address long-term policy issues by looking at the complete waste cycle. Such an approach would be applicable to modeling solid waste at the state or national level where policy decisions affecting waste management are being made.

Macro Material Flow Modeling Structure

The materials cycle can be shown schematically in Figure 4. The boxes in Figure 4 represent material states, while the arrows represent transformation processes. The processes are net energy users except where explicitly identified by the E+ symbol.

Another way of looking at materials production and waste production is in a matrix format. Thus waste type becomes one coordinate of a matrix and the sector of waste origin is defined as the other coordinate. Such a matrix is shown schematically in Figure 5. The matrix structure is useful because it obviously lends itself to mathematical modeling. Because the MMFM approach models the material flows through all of the components of the integrated waste management system, it is very useful in evaluating alternative system configurations and in ensuring that the various system components interface appropriately with each other.

To calculate the input and output for each cell in the matrix an objective function can be developed to account for the transformation of materials to wastes. To model such a process, the output of the process for a given material, for a given time period can be defined as a function of:

- The input material.
- A set of independent variables, such as gross national product, per capita income, population or population density, regulatory factors, and/or climate.

- Activity of related processes in other sector/functional waste type categories (i.e. other cells in the matrix) but not directly in the input or output chain of the particular process in question.
- Past outputs of the process.

This is shown schematically in Figure 6.

Macro Material Flow Modeling Implementation

The modeling principles discussed above have not yet been applied to a municipal solid waste case. They have been implemented at the Hanford Site and are currently being used to manage hazardous and solid wastes. The Hanford Model is optimized to track wastes and minimize treatment and disposal disposal costs (5). It also produces management reports as required by the Department of Energy, the EPA, and the Washington State Department of Health. An overview of the waste management system simulated by the Hanford Model is shown in Figure 7. The Model is programmed in the SimScript simulation language, a high level programming language with many features in common with STELLA (as used in the Puerto Rico Model).

Pacific Northwest Laboratory and California Polytechnic State University are collaborating to develop applications of Macro Material Flow Modeling for municipalities and state government. It is expected that future models will combine some of the features of the Puerto Rico STELLA Model and the Hanford Site SimScript Model.

CONCLUSIONS

Computer modeling of solid waste management systems has evolved from one dimensional models that focused on costs or materials routing to multidimensional models which can track materials and wastes throughout their entire use cycle. Such models will allow solid waste planners and decision-makers to manage wastes on a more cost effective basis.

ACKNOWLEDGMENTS

The primary author gratefully acknowledges the support of the Pacific Northwest Laboratory Affiliate Staff Scientist Program which has supported my involvement with the application of Macro Material Flow Modeling to municipal solid waste problems. Pacific Northwest Laboratory is operated by Battelle Memorial Institute for the U.S. Department of Energy. Brown and Caldwell Consultants, Pleasant Hill, California and the Puerto Solid Waste Management Authority are also acknowledged for their support of the development of the STELLA Puerto Rico Solid Waste Model.

DISCLAIMER

The mention of specific computer programs or operating systems does not constitute a recommendation or endorsement by California Polytechnic State University or Pacific Northwest Laboratory.

REFERENCES

1. Vigil, S.A., Zevely, J.A., Yeaman, R.; "Microcomputer Model for Solid Waste Planning," in *Public Works*, February 1987; pp 42-45.
2. Bracken, R.; "Virtual Garbage: Computer Simulation in Solid Waste Planning," in *Public Works*, August 1994; pp 50-52.
3. Vigil, S.A., Theisen, H.; "Graphical Integrated Solid Waste management Model for Puerto Rico," in *Proceedings of the 1992 National Solid Waste Processing Conference*, American Society of Mechanical Engineers, New York, 1992.
4. Holter, G. M., Stapp, D.C., Shaver, S.R.; "Application of Macro Material Flow Modeling to Regional Solid Waste Modeling," in *Proceedings of the 87th Annual Meeting and Exhibition of the Air and Waste Management Association*, Cincinnati, Ohio, June 19-24, 1994.
5. Holter, G. M., Stiles, D. L., Shaver, S. R., et al.; "Logistics Modeling of Future Solid Waste Storage, Treatment, and Disposal," in *Proceedings of the 1993 Pacific Basin Conference on Hazardous Waste*, Honolulu, Hawaii.

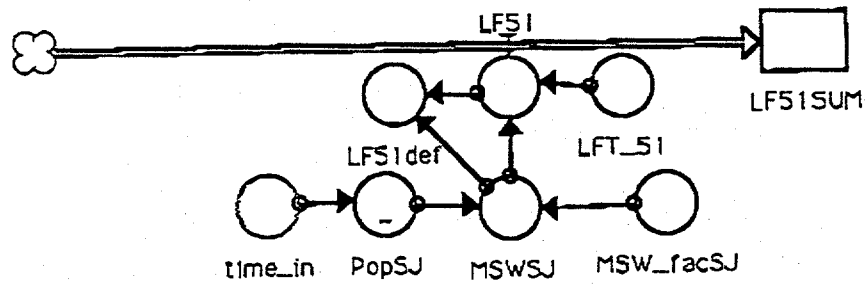


Figure 1 - San Juan Logic Diagram (Existing System)

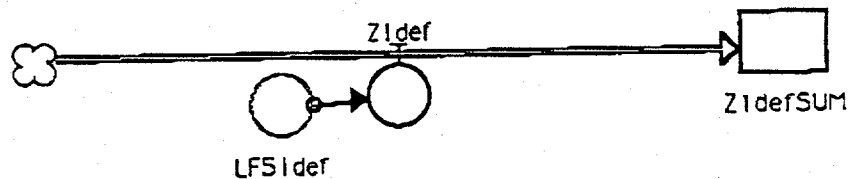


Figure 2 - Zone 1 Deficit Summary (Existing System)

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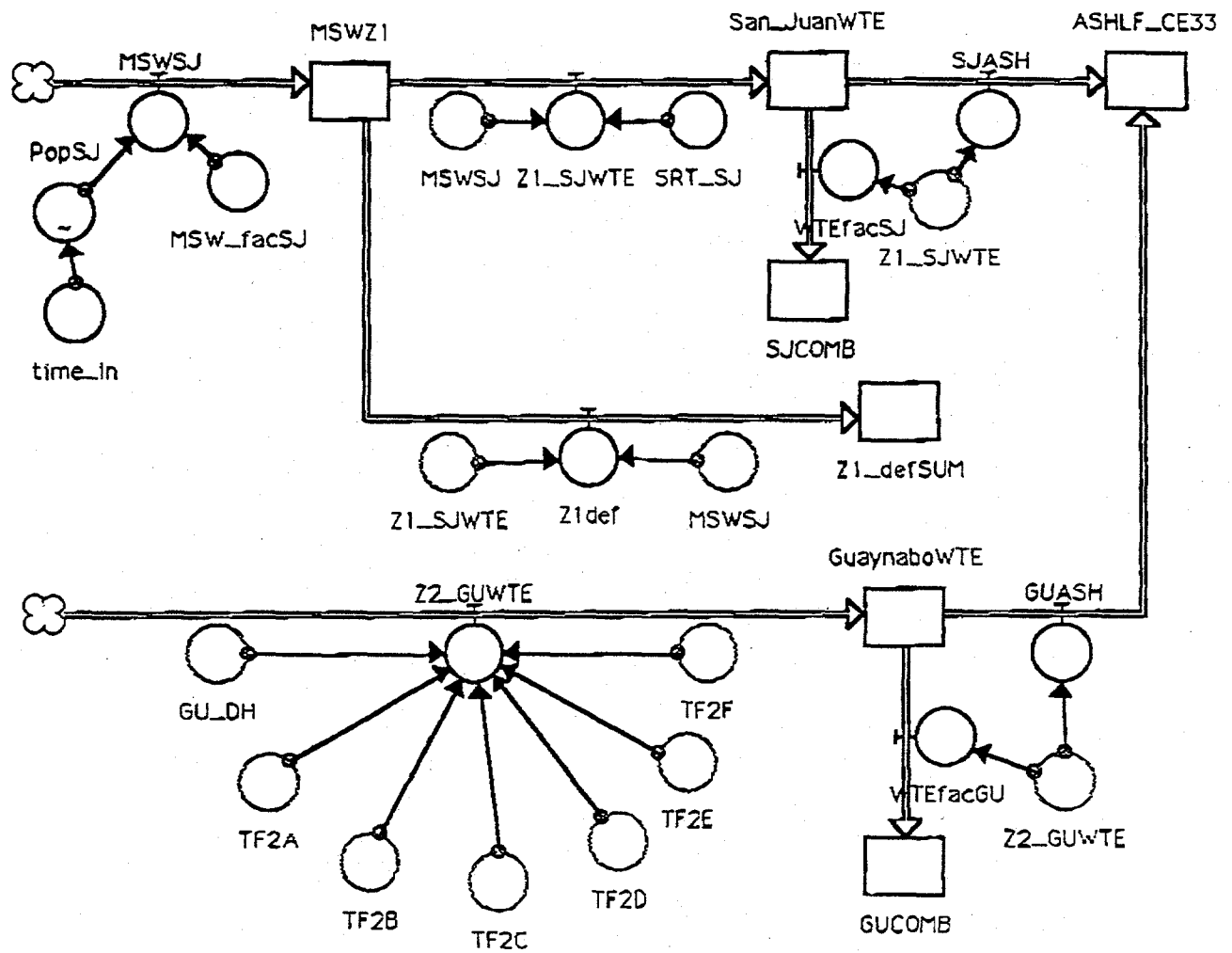


Figure 3. San Juan and Guaynabo Logic Diagrams (Proposed System)

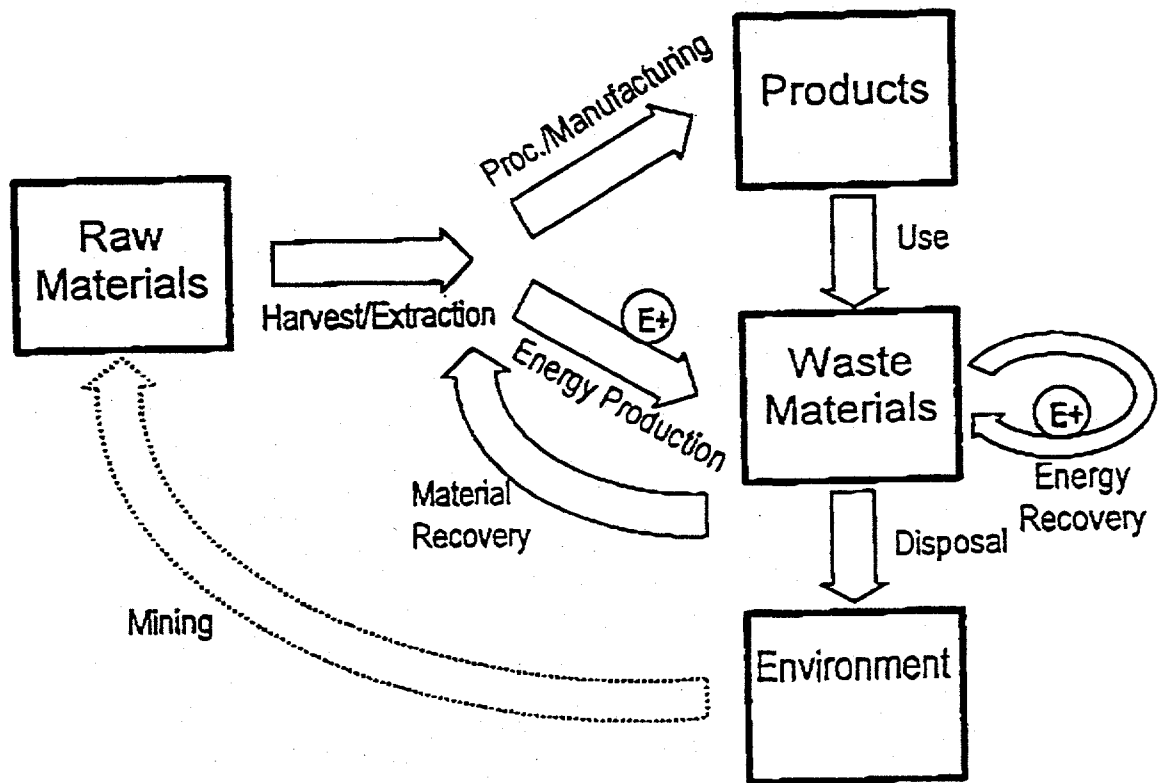
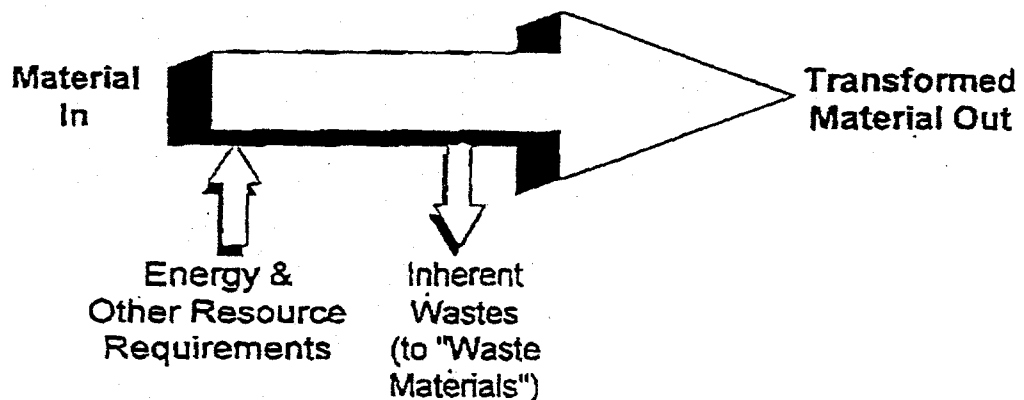


Figure 4. The Materials Flow Process

<u>Functional Waste Types</u>	<u>Sectors</u>									
	Household/Res.	Commercial	Industrial	Energy	Construction	Ag./Forestry	Medical	Government	Transportation	Mining
Packaging										
Conversion Loss/Scrap										
Used/Failed/Defective										
Processing Residuals										
Debris										
Food Waste										
Yard Waste										
General Trash										

Figure 5. The Solid Waste Matrix



Output = f (input, independent variables, related processes in other sector/functional waste type categories, past outputs, etc.)

Figure 6. Simplified Solid Waste Process Model

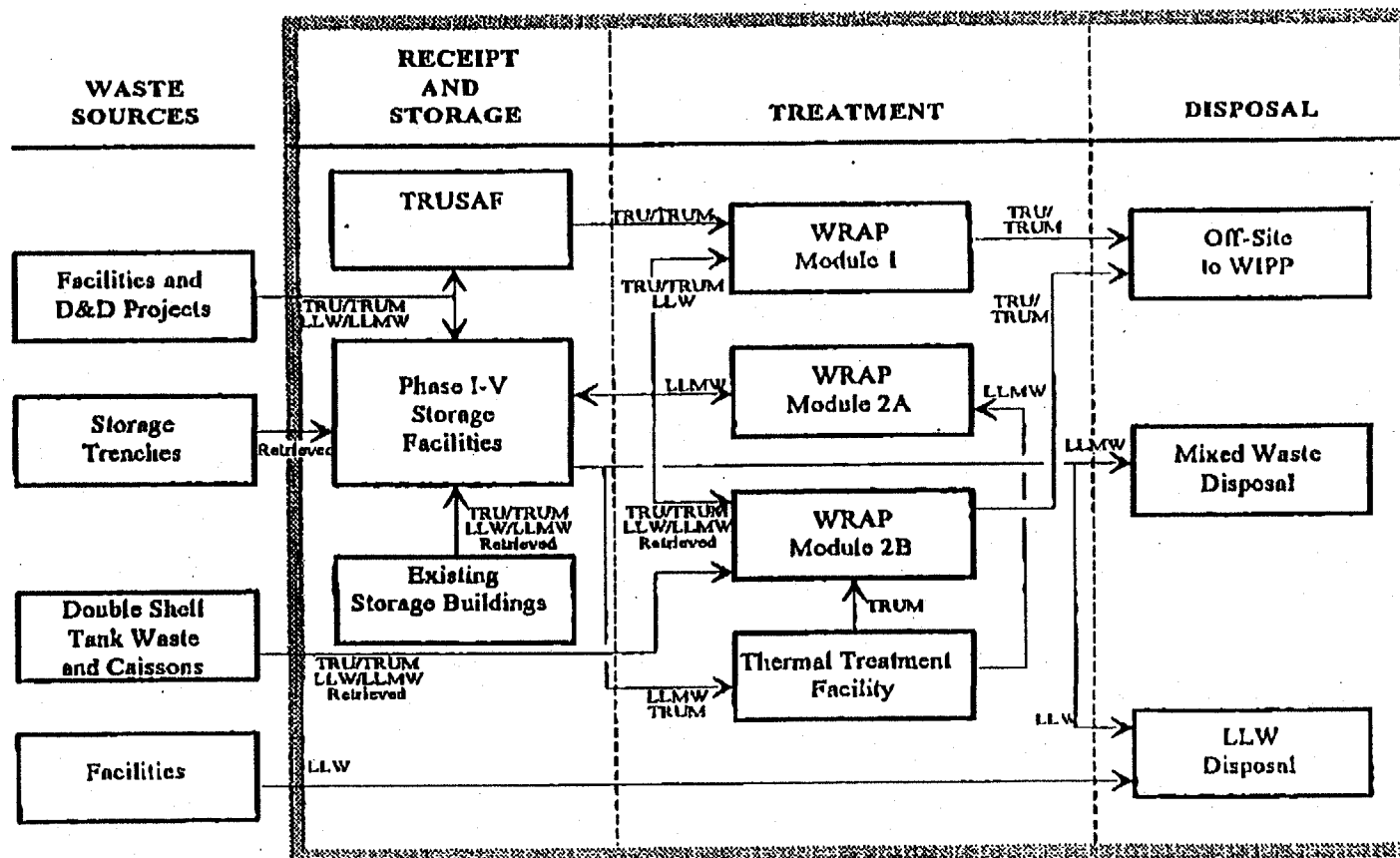


Figure 7. Waste Management System Simulated by the Hanford Model